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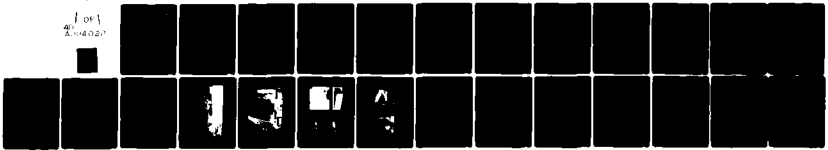

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DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Maryland 20084

EVALUATION OF NAVIGATION SYSTEMS DURING TRIALS CONDUCTED ON THE USS SPIEGEL GROVE (LSD 32)

by

Grant A. Rossignol

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SHIP PERFORMANCE DEPARTMENT

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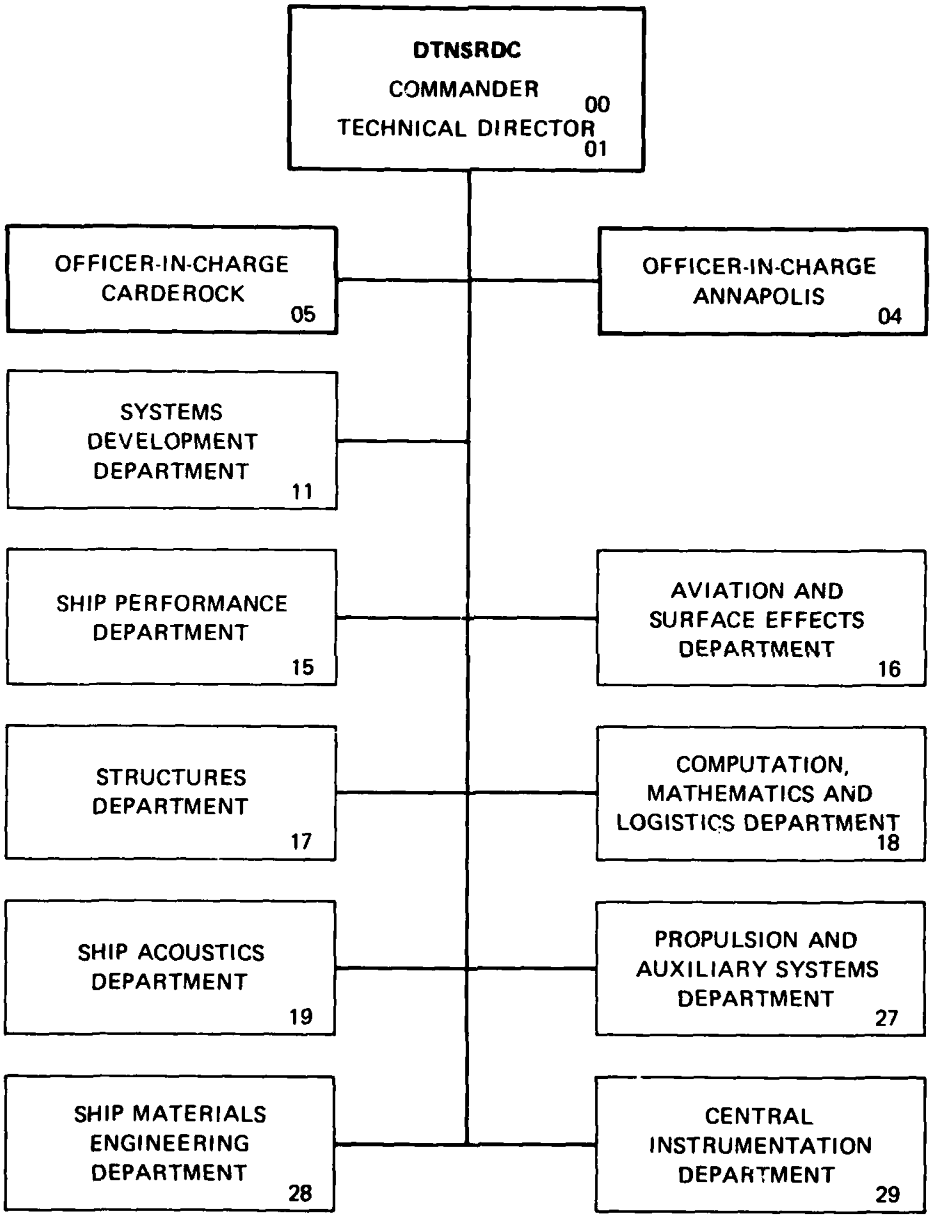

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This report presents the results of an evaluation of inertial navigation systems (INS) and a satellite navigation (SATNAV) system conducted during trials on the USS SPIEGEL GROVE (LSD 32). INS and SATNAV ship tracking data were compared to AERIS shore tracking data provided by the Naval Coastal Systems Center (NCSC). The results show that inertial navigation and SATNAV systems can provide an accurate and reliable method of obtaining ship tracking

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data independent of external equipment and operation area relative to shore. Experience gained during this evaluation should further improve the applications of INS and SATNAV tracking to future trials. Nothing in this report should be construed to be either a positive or negative endorsement of any specific hardware evaluated.

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ABSTRACT

This report presents the results of an evaluation of inertial navigation systems (INS) and a satellite navigation (SATNAV) system conducted during trials on the USS SPIEGEL GROVE (LSD 32). INS and SATNAV ship tracking data were compared to AERIS shore tracking data provided by the Naval Coastal Systems Center (NCSC). The results show that inertial navigation and SATNAV systems can provide an accurate and reliable method of obtaining ship tracking data independent of external equipment and operation area relative to shore. Experience gained during this evaluation should further improve the applications of INS and SATNAV tracking to future trials. Nothing in this report should be construed to be either a positive or negative endorsement of any specific hardware evaluated.

ADMINISTRATIVE INFORMATION

This work was authorized by the Amphibious Assault Landing Craft Program Office (AALC) of the Systems Development Department of the David W. Taylor Naval Ship Research and Development Center (DTNSRDC) and funded by the Naval Sea Systems Command (NAVSEA PMS 377). Additional funding was provided by the DTNSRDC Ship Performance and Hydromechanics Program. The work was performed under DTNSRDC Work Unit Numbers 1180-950, 1180-952, and 1500-104.

INTRODUCTION

The David W. Taylor Naval Ship Research and Development Center (DTNSRDC) participated in trials on the USS SPIEGEL GROVE (LSD 32). These trials were conducted in support of the Amphibious Assault Landing Craft (AALC) Program of the Naval Sea Systems Command (NAVSEA) and the AALC Office of the Systems Development Department, DTNSRDC. As part of these trials, an evaluation was conducted of two inertial navigation systems (INS) and a satellite navigation (SATNAV) system. These navigation systems were installed on board the ship and were used to track the ship's path during coursekeeping maneuvers. The ship's path was also tracked by shore stations (AERIS) maintained by the Naval Coastal Systems Center (NCSC) so that the comparative relative accuracies of the shipboard navigation systems could be determined.

The utilization of INS and SATNAV tracking during ship maneuvering trials represents a completely unique technique at DTNSRDC. Previously, any accurate ship tracking was provided by shore stations. A severe limitation on trial operating

areas was thus imposed since accurate shore station tracking is limited to 10-12 nautical miles from shore. As a result, the effects of various environmental factors (wind, waves, current, and water depth) on ship maneuvering have not been properly investigated. INS and SATNAV tracking provides a method of tracking the ship's path through various maneuvers independent of the ship's location or weather conditions. In addition, no equipment other than that installed on the ship is required. The accuracy of the results is mainly determined by the INS software, the quality of the particular INS, the time allowed for proper INS initialization, and the frequency of INS updates from information provided by the SATNAV system. Proper installation of the various INS and SATNAV components on the ship prior to a trial is also critical to obtaining accurate results. This evaluation represents only the first of a series of such efforts. Future evaluations will investigate:

a. the accuracy of INS and SATNAV tracking during various maneuvers (turning, etc.);
b. the relative merits of various types of inertial navigation systems;
c. the benefits of different INS software;
d. limitations of INS and SATNAV tracking;
e. the value of SATNAV tracking (using dead reckoning) without INS tracking;
f. the simplification of INS recording devices into a more portable, compact unit;
g. the accuracy of INS pitch, roll, and heading measurements;
h. the accuracies of various SATNAV systems;
i. the optimum installation procedures on a ship.

Although INS and SATNAV tracking provides the ship's absolute position (latitude and longitude), the path of the ship relative to the starting location of a particular maneuver is the primary requirement of ship tracking during trials. Therefore, relative accuracy of navigation systems is more important for most trial applications than is absolute accuracy. Certain special trials may, however, require absolute position fixes. Some examples of these trials are station-keeping, mine sweeping, cable laying, and shallow water maneuvering.

DESCRIPTION OF INSTRUMENTATION

The instrumentation used for the evaluation consisted of two inertial navigation systems (INS), a satellite navigation (SATNAV) system, and a transmitting transponder which is part of the AERIS shore tracking range. The rest of the AERIS

shore tracking range consists of two receiving shore stations and a data processing center at NCSC. The inertial navigation systems were a Litton Guidance and Control Systems Division LGN 500 and a Litton Aero Products Division LTN 51. Both are gyroscopically stabilized systems as opposed to strap-down systems. The LTN 51 is the type of INS which is commonly used for airborne applications and has a drift rate of approximately 1.0 nautical mile per hour. The LGN 500 is similar to the LTN 51 but with important differences. The basic inertial measurement unit (IMU) is the same type as the LTN 51 but with slightly better precision. The main differences are in the programming in the computer circuitry. The LTN 51 initialization procedure required the ship to be motionless for best results while the special marine software of the LGN 500 allowed underway initialization. The drift rate of the LGN 500 is less than 1.0 nautical mile per 14 hours, as a result of the improved IMU and special marine software. The drifts of both INS's were mimimized by frequent updates of the latitude and longitude of the ship's position. These latitude and longitude position fixes were provided by a Navigation Communication Systems, Incorporated (NCS) Model 2800 Satellite Navigation System. This SATNAV system consists of a SATNAV receiver, a small computer, and an antenna. Satellite position fixes were obtained every three hours on the average. A paper printer connected to the SATNAV receiver provided the necessary information. EM log and gyrocompass cables connected to the back of the SATNAV receiver provided automatic ship's speed and heading input. A Litton field engineer operated the INS and SATNAV equipment. All of the equipment was installed in the DTNSRDC Portable Data Collection Center (PORDACC) trailer, which was installed on the helicopter deck of the ship. The SATNAV antenna was installed on the port crane and the AERIS transponder was installed on top of the PORDACC trailer. Figure 1 shows the SPIEGEL GROVE, while Figure 2 shows the PORDACC trailer location. Figure 3 shows the LGN 500, LTN 51, and the NCS SATNAV receiver. Figure 4 shows the SATNAV antenna and the AERIS transponder as installed on the ship.

MEASUREMENTS AND DATA REDUCTION TECHNIQUES

Digital time histories of the following signals were recorded on a DEC computer system disk pack:

1. longitudinal position coordinate (LGN 500)
2. transverse position coordinate (LGN 500)
3. longitudinal position coordinate (LTN 51)

4. transverse position coordinate (LTN 51)

The capability existed for real-time data reduction during the trial by virtue of the DEC computer system installed in the PORDACC trailer. However, time limitations imposed by the ship deployment schedule did not permit much data reduction to be accomplished onboard the ship. Instead, most data reduction was performed at DTNSRDC after the trial. The INS longitudinal and transverse position coordinates were obtained as latitude and longitude once per second. These values had to be converted to distance traveled relative to the starting point of the particular maneuver. The equations used are given in Appendix A. The INS to computer digital interface designed for this trial only permitted data to be obtained for one INS at a time. Thus, simultaneous comparisons were not possible for the LTN 51 and the LGN 500.

AERIS shore tracking data was collected at NCSC. Time, longitudinal position coordinate, and transverse position coordinate were collected at one second intervals most of the time the ship was on the tracking range. During periods of time when the ship was headed directly towards shore, no data was collected due to the transmitting transponder location. The AERIS data was then processed to correlate with the various ship maneuvers.

TRIAL CONDITIONS AND PROCEDURE

The trial operation area was in the Gulf of Mexico off the coast of Panama City, Florida between the latitudes of 30°00' and 30°10' north and the longitudes of 85°46' and 85°54' west. The water depth varied from 60 to 110 feet (18.3 to 33.5 meters). The operation area was also between two NCSC environmental platforms located 3 and 12 miles offshore. The seas ranged from 0.5 to 2.0 feet (0.2 to 0.6 meters) and the wind speed varied from 5 to 12 knots. The NCSC platforms were instrumented to collect sea and wind data of importance. The trial was conducted on 22 and 23 August 1979.

During this evaluation, only coursekeeping maneuvers were conducted for ship speeds ranging from 8 to 18 knots. The procedure used in conducting these maneuvers was as follows:

1. bring the ship to a constant speed;

2. have the helmsman steer a steady course, while trying to minimize rudder action;

3. collect approximately 5 minutes of data.

PRESENTATION OF RESULTS

Figure 5 presents a comparison of the relative accuracy between the LGN 500 INS and the AERIS shore tracking. As can be seen, the agreement is excellent. The scatter in the ship's path is due to the fact that a relatively short coursekeeping maneuver is blown up to show the detail of the tracking comparison; the ship actually maintained a fairly constant path. Unfortunately, this figure represents the only comparative data obtained for both the LGN 500 INS and the AERIS shore tracking. The digital interface between the LGN 500 and LTN 51 INS's allowed data to be recorded from only one of the INS's at a time. During all of the other coursekeeping maneuvers for which LGN 500 data was collected, AERIS shore tracking data was not obtained due to physical limitations (ship location on the range, transponder location, etc.)

Figures 6 through 11 present comparative accuracies between the LTN 51 and AERIS shore tracking. As can be seen, the agreement is excellent for a ship speed of 8 knots and then degrades as the ship speed increases. This is possibly due to the LTN 51 INS drift rate being affected by increases in ship speed. Regardless, the mean path of the ship from the LTN 51 INS agrees fairly well with the AERIS shore tracking. For any type of ship maneuver (coursekeeping, turning, zigzag, etc.), construction of a reasonably accurate mean ship path should be possible from LTN 51 INS data. Modifications of the LTN 51 INS software package should yield even better data by virtue of better initialization and update procedures. These accuracies are surprisingly good considering that the LTN 51 is an INS designed for commercial aircraft applications.

The accuracy of tracking data obtained from both inertial navigation systems could have been affected by the frequency and quality of SATNAV fixes. Although the performance of the Navigation Communication Systems, Inc. Model 2800 Satellite Navigator was excellent during the trial, a better location of the antenna could have produced more frequent position fixes. As with the INS operation, valuable experience was gained. Dead reckoning position fixes were also provided by the SATNAV system in between satellite passes. This was possible because of the automatic EM log and gyrocompass inputs. Possible errors in the EM log output could have produced SATNAV position fix errors which would have been passed on to the INS's. During the entire evaluation, both the inertial navigation and SATNAV systems stayed in excellent working order (however, spare INS parts were available if needed). The air conditioning in the PORDACC trailer probably helped.

The shore tracking data was, and shall continue to be, the basis for comparative navigation system evaluations. The quality of the data on the AERIS range has been well established during past NCSC evaluations. As a result, this evaluation did not intend to investigate the quality of AERIS shore tracking data. This evaluation did, however, show that some limitations in obtaining AERIS data did exist. The two major limitations were transponder placement on the ship and ship location on the AERIS range. The transponder was located on top of the PORDACC trailer. Ship superstructure forward of this location and both ship's cranes caused some blockage of data transmission at times. Since the AERIS tracking relies on line-of-sight tracking, some ship headings relative to shore (mainly 180 degrees) caused data loss. During some of the maneuvers, the ship operated off of the AERIS range (or in fringe areas). As a result, no AERIS data was obtained during these maneuvers. Future evaluations should keep ship location in consideration.

This evaluation represents only the first of many planned DTNSRDC efforts concerning INS and SATNAV tracking. Of the various navigation or tracking systems presently available, the combination of INS and SATNAV tracking seems to offer the only method of ship tracking independent of shore. LORAN C may provide reasonable tracking at certain locations depending upon the LORAN C coverage, but evaluations will have to be conducted. Future INS and SATNAV evaluations should be concerned with the effects of various ship maneuvers on data accuracy, improved operational and installation procedures of equipment, and simplification of recording devices. In addition to evaluations of the tracking capability of INS, the INS dynamic measurement of pitch, roll, and heading of a ship in a seaway needs to be evaluated as compared to accepted DTNSRDC standards of measurement (MARK IV stable platform and Humphrey gyro package). The accuracies of INS measurements should exceed those of present DTNSRDC systems. The most important of these three measurements could be the ship's heading. At present, an accurate 360 degree measurement of heading requires interface with the ship's steering gyrocompass. This interface often has to be made by a ship IC-man, eliminates DTNSRDC independence of ship's systems, requires on ship calibration, and could interfere with the gyrocompass performance. INS heading accuracies of 0.1 degree are possible as compared to 0.25 to 0.5 for most gyrocompasses. Since all maneuvering trials and most seakeeping trials require the measurement of ship's heading, INS utilization will clearly be of value. Another extremely useful measurement provided by inertial navigation systems is the ship speed and should be checked against ship EM logs and shore tracking values.

The merits of variations in INS and SATNAV software packages should also be evaluated as well as different types of systems. Strap down INS may prove to offer advantages over gyrostabilized INS, particularly in cost. The improved accuracy of dual channel SATNAV tracking may also prove to be of significantly greater value than single channel SATNAV.

The quality of dead reckoning position fixes, provided by SATNAV systems in between satellite fixes, needs to be evaluated. Since the ship's EM log and gyrocompass outputs can be directly connected into the back of most SATNAV receivers, calculations of the ship's position can be made relative to the last satellite fix. By calibrating the ship's EM log at the beginning of a trial, the accuracy of these dead reckoning position fixes can be maximized. Dead reckoning fixes obtained at frequent intervals (every 10 seconds) may thus provide reasonably accurate ship tracking relative to the beginning of a particular maneuver without using INS tracking. For certain applications, SATNAV tracking alone can therefore provide a convenient method of ship tracking in any operation area. As the number of navigation satellites increases, the value of SATNAV tracking will further increase. Once the NAVSTAR system is fully operational (by 1985), nearly continuous SATNAV position fixes will be possible.

CONCLUSIONS

The following conclusions are drawn from this evaluation of inertial navigation and SATNAV systems:

1. The agreement was excellent between the LGN 500 INS and the AERIS shore tracking data for the limited comparison made.

2. The data obtained from the LTN 51 INS agrees well with AERIS data at low ship speeds, but displays significant scatter as the ship speed increases. The mean path does, however, maintain reasonable agreement.

3. The frequency and quality of position fixes obtained from the SATNAV system were sufficient for proper INS initialization and updates in spite of less than optimum antenna placement.

4. Neither of the inertial navigation systems nor the SATNAV system failed to operate properly during the entire evaluation.

5. Excellent AERIS shore tracking data was obtained most of the time that the ship operated on the AERIS range. The only losses in shore tracking data seemed to occur because of the location of the transponder on the ship.

6. The quality of INS and SATNAV tracking was completely unaffected by ship location, weather, or time of day during this evaluation. Only ship speed seemed to affect the results.

RECOMMENDATIONS

The following recommendations are made regarding future evaluations of inertial navigation and SATNAV systems:

1. Compare INS and SATNAV tracking with shore station tracking during various ship maneuvers at a range of ship speeds.
2. The shore tracking transponder and SATNAV antenna should be located on the ship so that no shielding by ship superstructure occurs.
3. Modifications to the digital interface between the INS and DTNSRDC recording devices should be made so that future evaluations will not require a computer to be used to collect INS data. A portable data collection device should be assembled to include a printer and digital recorder (either tape or disk).
4. Compare tracking data from different types of inertial navigation and SATNAV systems.
5. Evaluate the quality of relative dead reckoning SATNAV tracking.
6. Compare INS pitch, roll, and heading measurements with accepted DTNSRDC standards. Both the magnitudes and frequency responses of the measurements should be compared.
7. Improvements in data accuracy obtained by INS and SATNAV software modification should be investigated.
8. Any future evaluations should begin with a calibration of the ship's EM log. Uncertainties in the ship's speed can greatly affect the accuracy of INS and SATNAV tracking.

APPENDIX
FORMULAS AND EQUATIONS

Ship position coordinates.

The latitude, LAT, and longitude, LONG, of the ship's position were measured in degrees of minutes north and west, respectively. The transverse and longitudinal position coordinates of the ship's path, x and y, (initialized to zero at the beginning of each maneuver) were calculated by

$$x_i \begin{array}{l} \text{yards} \\ \text{meters} \end{array} = \begin{array}{c} 2026 \\ 1853 \end{array} \Delta LAT_i(\text{minutes})$$

and

$$y_i \begin{array}{l} \text{yards} \\ \text{meters} \end{array} = \begin{array}{c} 2026 \\ 1853 \end{array} \Delta LONG_i(\text{minutes}) \quad \cos\left[LAT_i(\text{degrees})\right]$$

The differences in latitude and longitude between the computed position and the initial position, ΔLAT_i and $\Delta LONG_i$, respectively, were calculated by

$$\Delta LAT_i = LAT_i(\text{minutes}) - LAT_o(\text{minutes})$$

and

$$\Delta LONG_i = LONG_i(\text{minutes}) - LONG_o(\text{minutes})$$

where LAT_o and $LONG_o$ are the latitude and longitude at the beginning of the maneuver and LAT_i and $LONG_i$ are the latitude and longitude at the i^{th} second of the maneuver (one position fix every second).

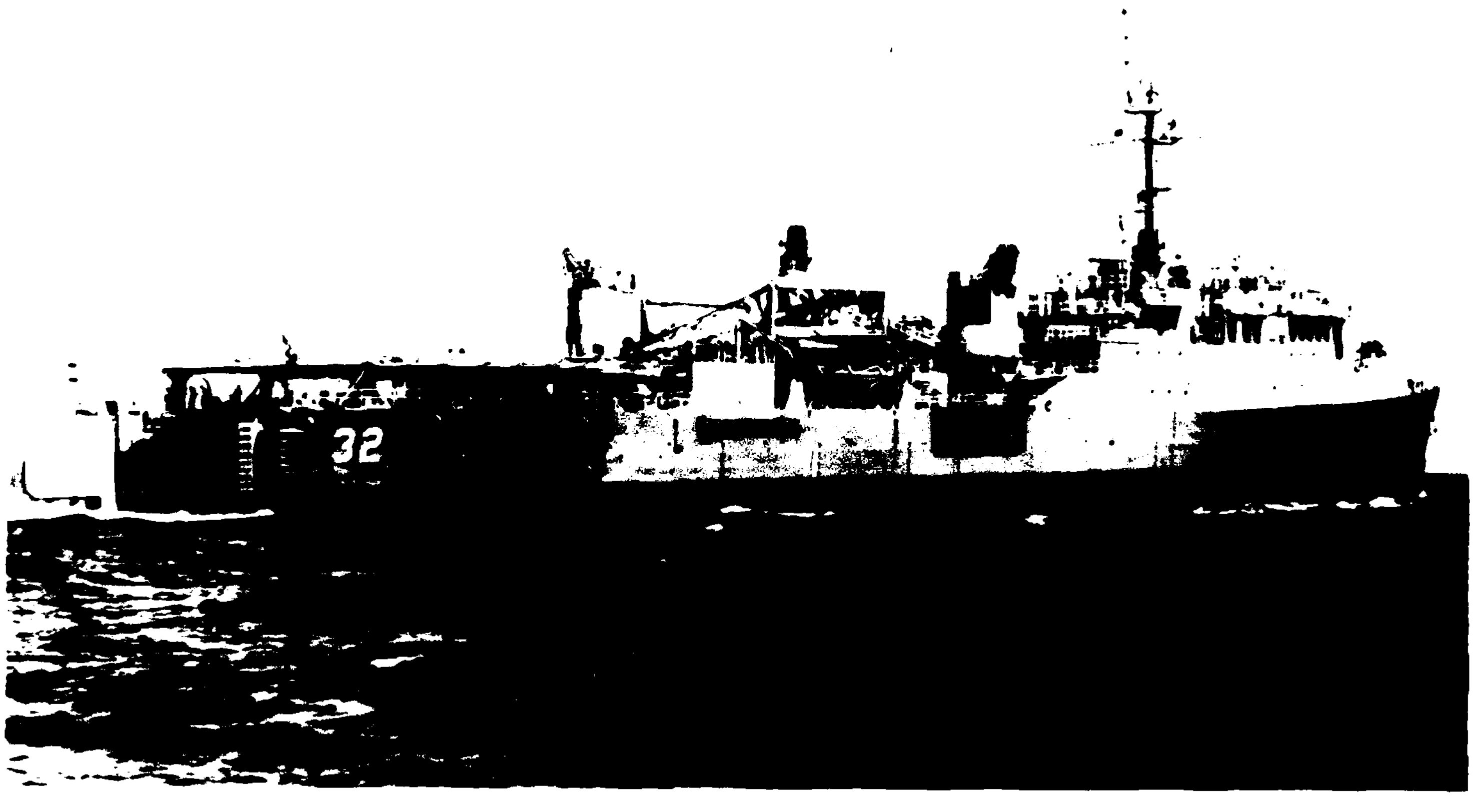
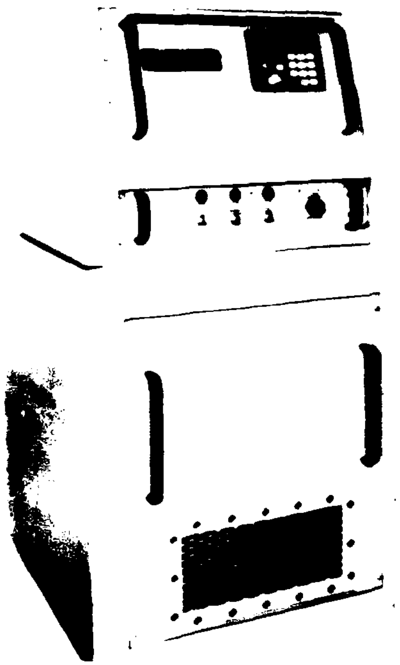
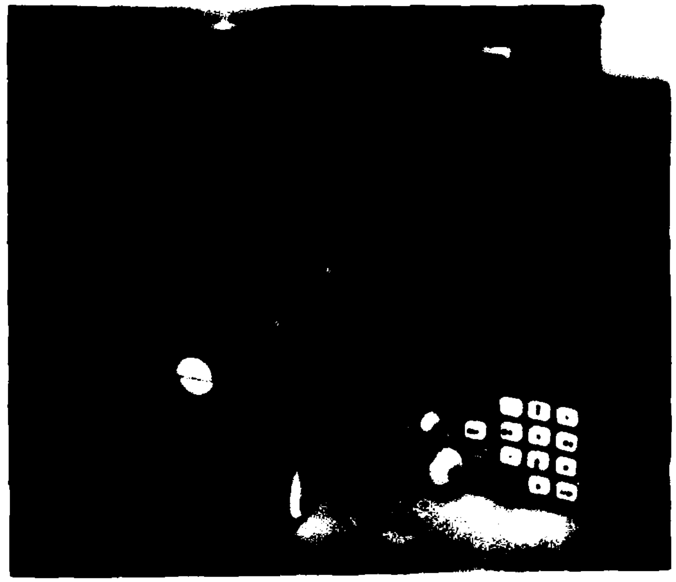


Figure 1 - Photograph of the USS SPIEGEL GROVE (LSD 32)

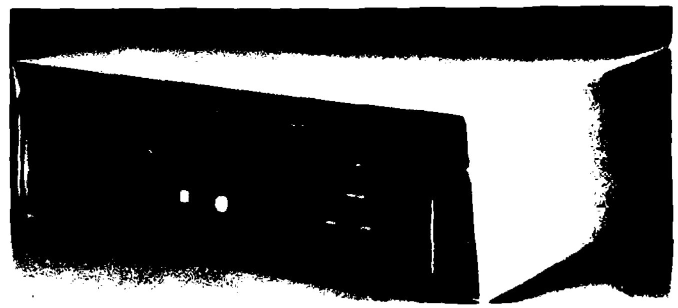
Figure 2 - Photograph of the PORDACC Location on USS SPIEGEL GROVE (LSD 32)



LGN 500 INS

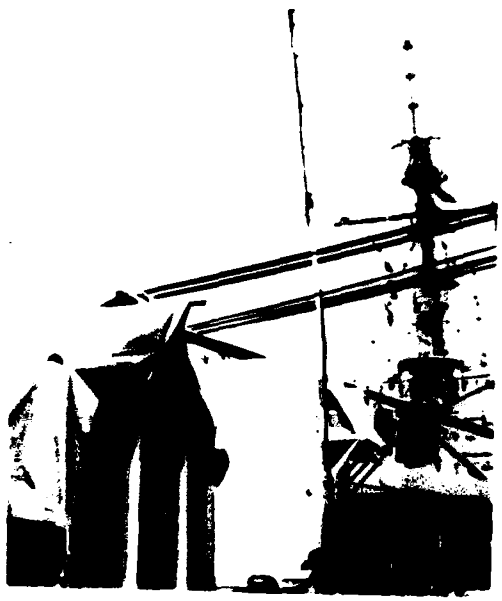


LTN 51 INS

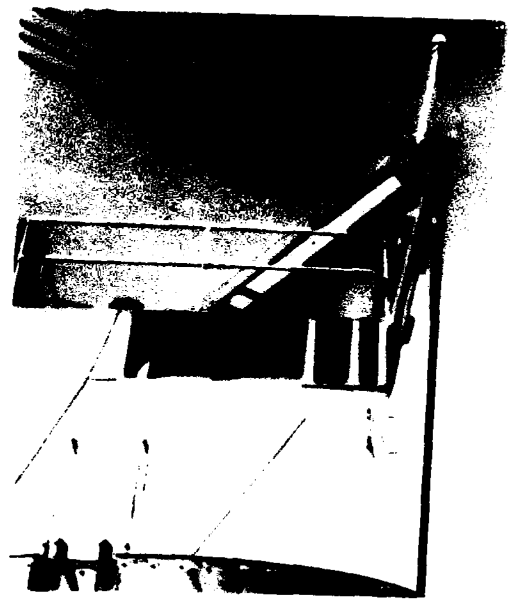


NCS 2800 SATNAV RECEIVER

Figure 3 - Photographs of the Litton LGN 500 and LTN 51 Inertial Navigation Systems and the NCS Model 2800 Satellite Navigation System



AERIS TRANSPONDER ON PORDACC



SATNAV ANTENNA ON PORT CRANE

Figure 4 - Photographs of the AERIS Transponder and NCS SATNAV Antenna as Installed on the USS SPIEGEL GROVE (LSD 32)

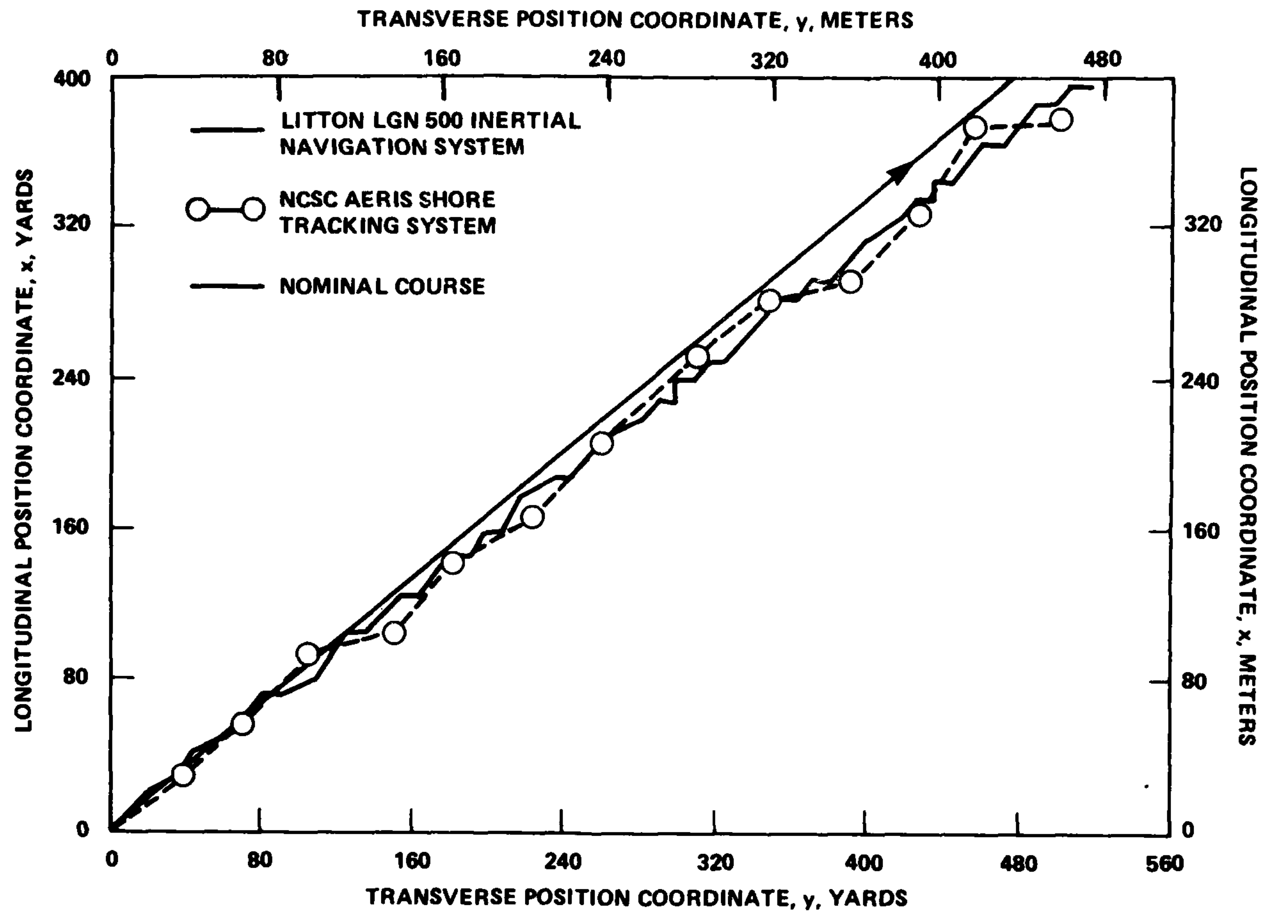


Figure 5 - Ship's Path During a Coursekeeping Maneuver Conducted on the USS SPIEGEL GROVE (LSD 32) at a Ship Speed of 10 Knots Comparing AERIS Shore Tracking and the LGN 500 Inertial Navigation System

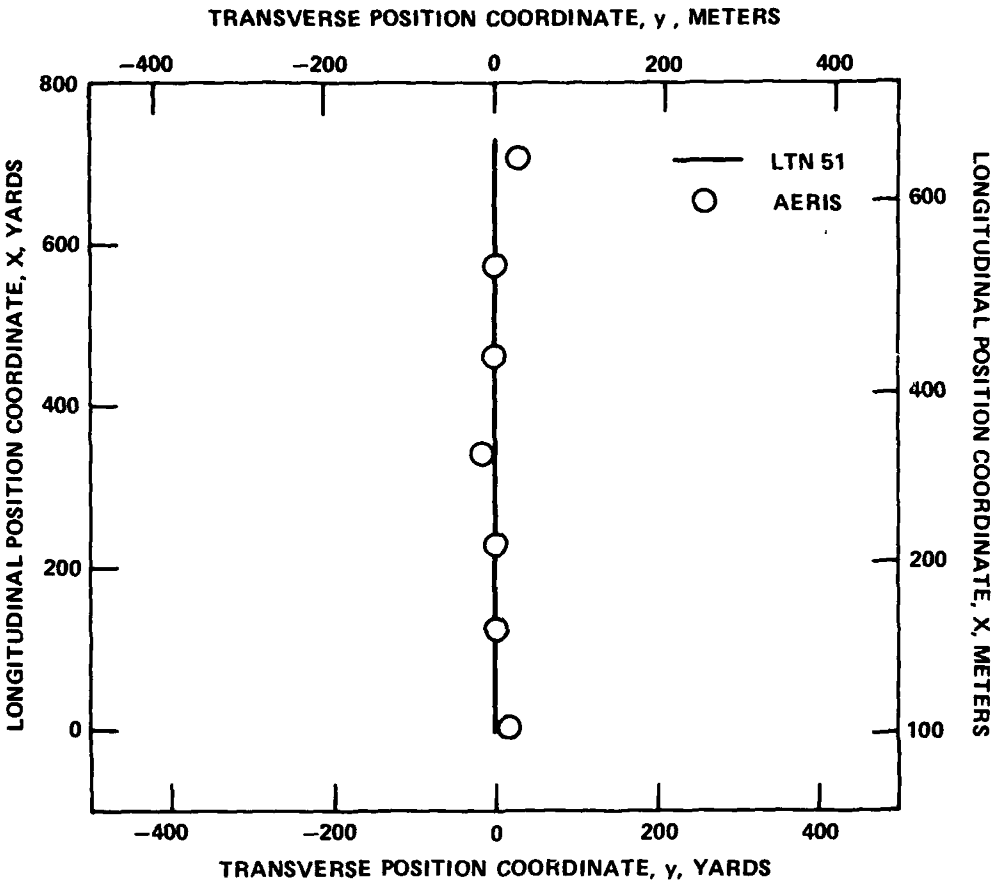


Figure 6 - Ship's Path During a Coursekeeping Maneuver Conducted on the USS SPIEGEL GROVE (LSD 32) at a Ship Speed of 8 Knots Comparing AERIS Shore Tracking and the LTN 51 Inertial Navigation System

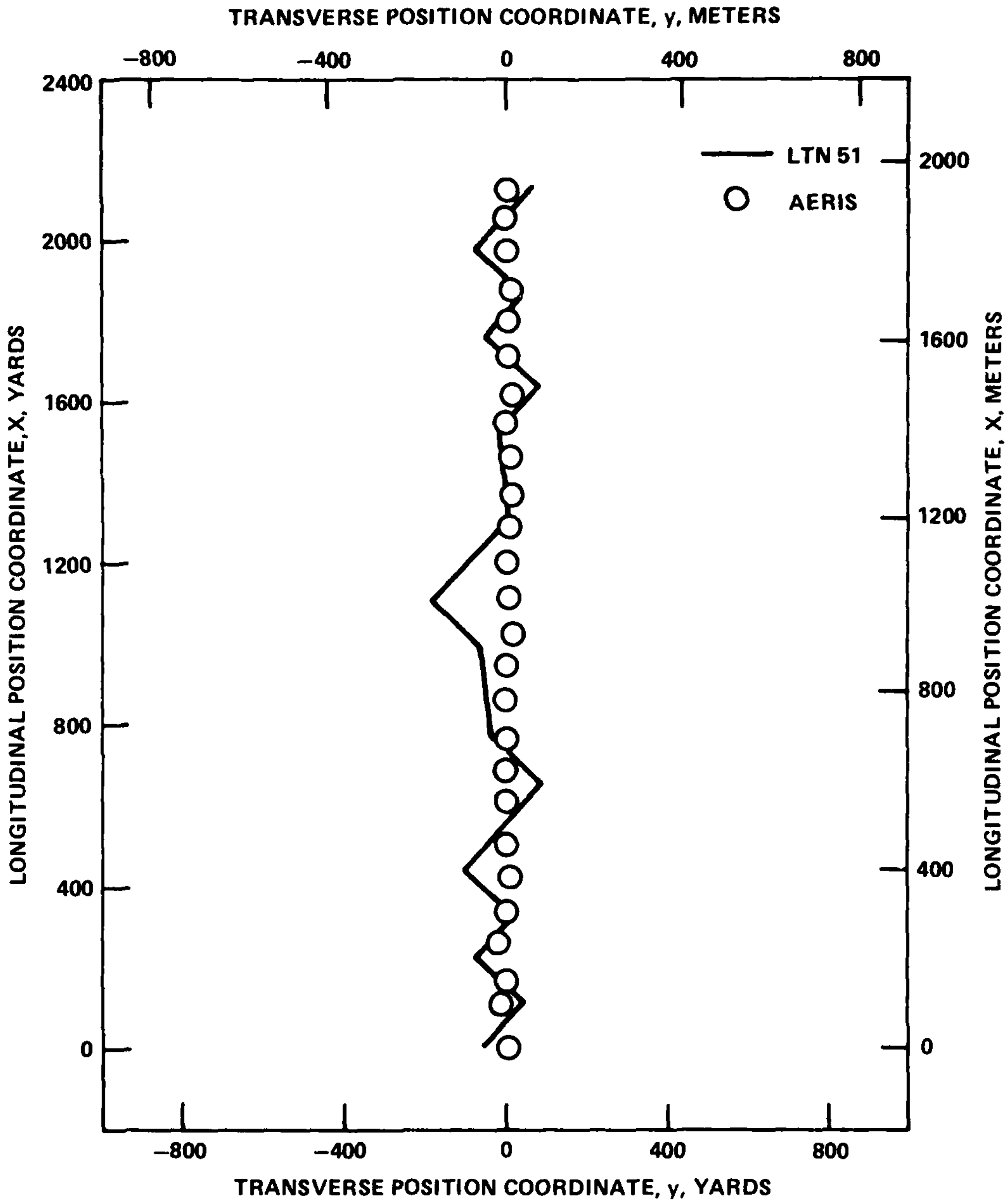


Figure 7 - Ship's Path During a Coursekeeping Maneuver Conducted on the USS SPIEGEL GROVE (LSD 32) at a Ship Speed of 10 Knots Comparing AERIS Shore Tracking and the LTN 51 Inertial Navigation System

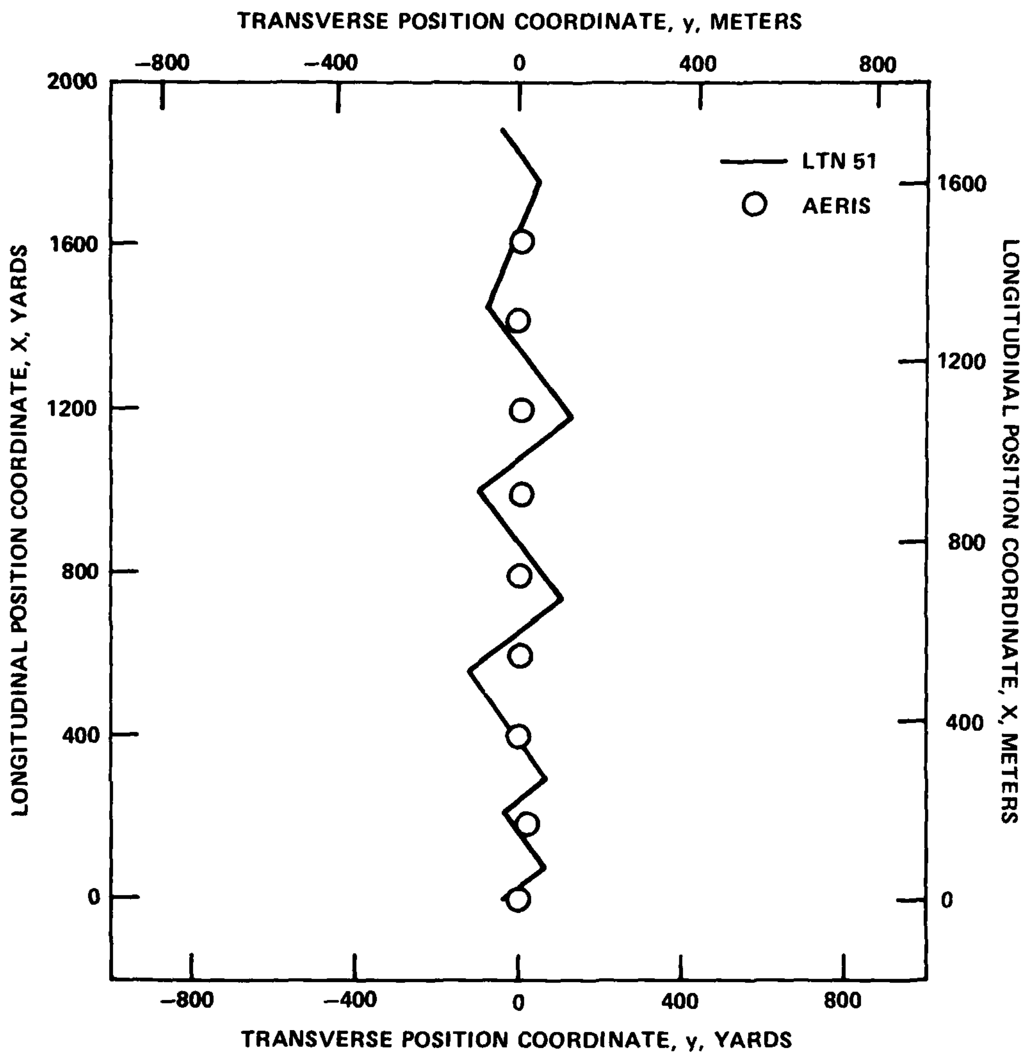


Figure 8 - Ship's Path During a Coursekeeping Maneuver Conducted on the USS SPIEGEL GROVE (LSD 32) at a Ship Speed of 14 Knots Comparing AERIS Shore Tracking and the LTN 51 Inertial Navigation System

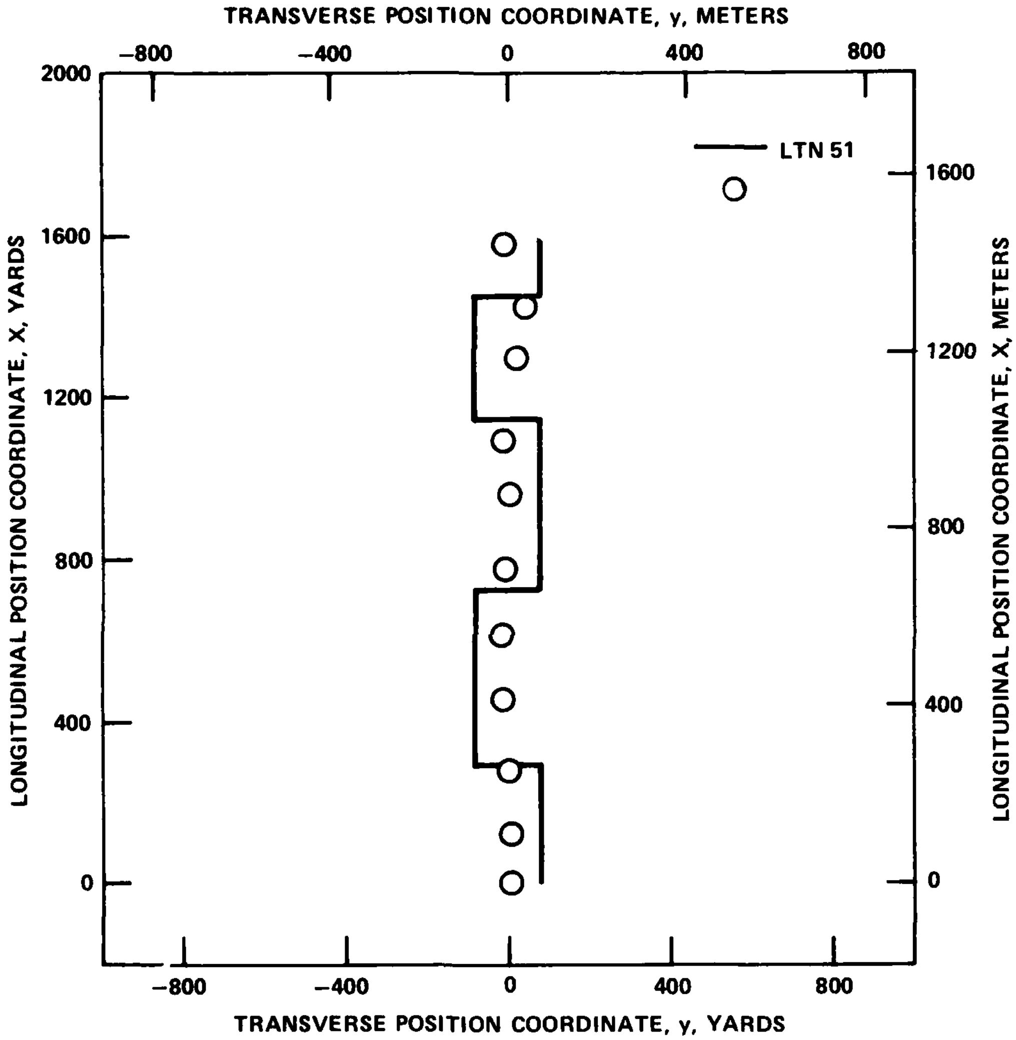


Figure 9 - Ship's Path During a Coursekeeping Maneuver Conducted on the USS SPIEGEL GROVE (LSD 32) at a Ship Speed of 16 Knots Comparing AERIS Shore Tracking and the LTN 51 Inertial Navigation System

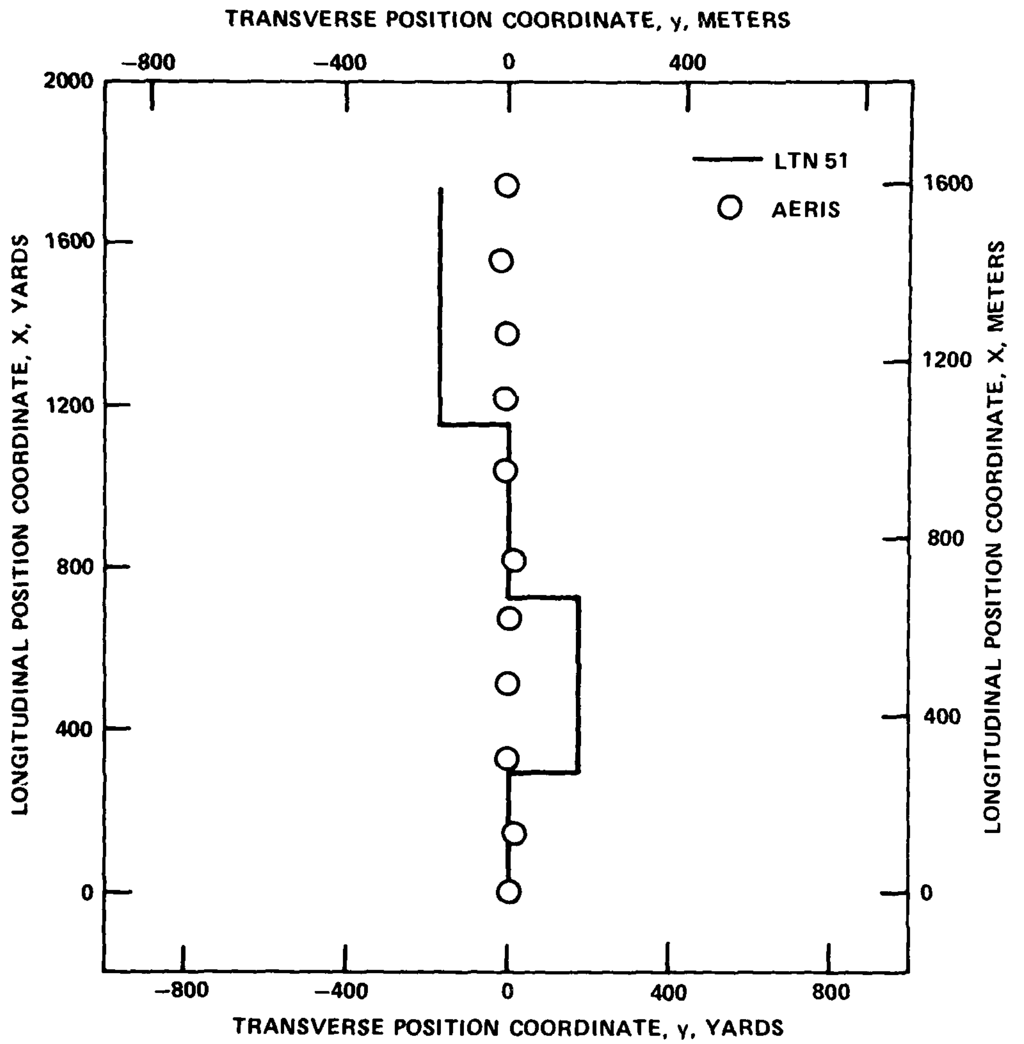


Figure 10 - Ship's Path During a Coursekeeping Maneuver Conducted on the USS SPIEGEL GROVE (LSD 32) at a Ship Speed of 18 Knots Comparing AERIS Shore Tracking and the LTN 51 Inertial Navigation System

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